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The accompanying table illustrates the maximal effects of the various drugs used on one of us, as expressed by the quantity of stimulus in C. G. S. units required to produce the threshold sensation of pain.

Although by the above described method only cutaneous sensations could be studied, we think that our observations are of some value in the study of the very important subject of analgesia. This research has been endowed in part by a grant from the Council on Pharmacy and Chemistry of the American Medical Association; the complete data with many tables will appear in the *Journal of Pharmacology and Experimental Therapeutics*, Vol. 7, No. 5, January, 1916.

¹ Claude Bernard, *Paris, C. R. Acad. Sci.*, **59**, 406 (1864).

² Fronmüller, *Klin. Stud. über die narcot. Arzneimittel*, Erlangen, 1869.

³ Baxt, *Arch. Anat. Physiol.*, 1869, p. 112.

⁴ Martin, Porter and Nice, *Psychological Review*, **20**, 194 (1913); Grobfield and Martin, *Amer. J. Physiol.*, **31**, 300 (1913); Martin, Bigelow and Wilbur, *Ibid.* **33**, 415 (1914); Martin, Wittington and Putnam, *Ibid.* **34**, 97 (1914).

⁵ Martin Grace and McGuire, *J. Pharmacol. Exp. Therap.*, **6**, 527 (1915).

⁶ von Frey, *Leipzig, Abh. Ges. Wiss.*, **66**, 186, 293 (1894); **67**, 166 (1895), and *J. Amer. Med. Ass.*, **47**, 695 (1906).

⁷ Straub, *Biochem. Zs.*, **41**, 419 (1912).

THE SURFACE-TENSION AT THE INTERFACE BETWEEN TWO LIQUIDS

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While working with Haber upon a theory of muscular motion it was found by Harkins that the capillary-tube method for the determination of surface-tension is very inaccurate whenever a basic solution is used. This method is also extremely sensitive to the action of dust particles and to the presence of certain impurities, since the surface involved in the measurement is very small. Of the other available methods the two best seem to be the measurement of surface waves and the determination of the weight of a falling drop. Of these two the former requires a very elaborate and expensive apparatus if the determinations are to be made with considerable accuracy, while on the other hand the drop-weight method makes use of comparatively simple apparatus and gives results which are reproducible with considerable accuracy.

The most complete treatment of the mathematical theory of the relation between the forms of drops and surface-tension is given in a book published in 1883 by Bashforth and Adams.¹ Much later than this,

in 1906, Lohnstein² applied the general theory to the special case of the hanging drop just before its fall and the residue left after its fall, and from the difference he obtained the magnitude of the falling drop itself. The equation which he used for the relation between the weight (W) of the falling drop and the surface-tension α is

$$W = 2\pi r \alpha f\left(\frac{r}{a}\right), \quad (1)$$

where r is the radius of the tip and a is the square root of the capillary-constant, and $f(r/a)$ is a function of r/a . Since $f(r/a)$ varies from 1.0 to 0.6, it is evident that neglect of this correction may cause errors as great as 40% in the surface-tension. It seems somewhat remarkable that in work with this method the correction has been neglected almost as often as it has been applied. Lohnstein determined the values of the function of r/a for different values of r/a , and his calculation of these corrections from a theoretical standpoint would seem to make it possible to use the drop-weight method as an independent method for the determination of surface-tension.

Unfortunately, however, when it becomes desirable to determine surface-tension, it is found that Lohnstein did not carry his calculations to a sufficient degree of accuracy to make this method available for determinations where an accuracy greater than 4% is desired. It is therefore important that this correction, which is a very fundamental one in work on capillarity, should be determined with a greater degree of exactness. Forms of apparatus devised by the writers seemed to make it possible to determine this correction experimentally under conditions which are more ideal than is possible when usual methods are used. Thus the substitution of experiments on the liquid-liquid interface for the ordinary method in which a liquid-air interface is used makes it possible to compare the drop-weight results with those obtained in a capillary tube of large bore (1.5 mm.) when the capillary rise is great enough (150 mm.) to give accurate measurements. Not only can the diameter of the large capillary be determined more accurately than that of the smaller tube used for measurements on a single liquid, but in addition it is much easier in the large tube to keep the surface of the meniscus in a pure condition. Then in the drop-weight determination itself the drop falls very much more slowly when it falls into a liquid than when it falls into a gas, so that there is less disturbance in the drop at the time of fall than when it breaks away at a relatively high speed. The corrections determined in this way are given in Table 1, and are shown in the form of a curve in figure 1. In the figure the ordinates

represent the values of the function of r/a , and the abscissae give the values of r/a . The complete circles represent Lohnstein's theoretically determined values, while the circles given in outline represent the new values determined experimentally. The figure shows that the experimental values give with Lohnstein's first two points for small values of r/a a much smoother curve than is given by his own theoretical values. The experimental values were determined by the use of a number of different liquids, and measurements were made both upon liquid interfaces and at the surface of a single liquid.

Morgan, who has carried out an extensive series of investigations³ on the drop-weight method, does not use the general Lohnstein rela-

TABLE I.
Experimental determination of the values of the function $f(r/a)$

<i>Point No.</i>	<i>r/a</i>	<i>f(r/a)</i>	<i>Interface</i>	<i>Temperature degrees</i>
1	0.281	0.709	Water: Ethyl Carbonate	25
2	0.366	0.685	Water: Benzene	25
3	0.441	0.672	Water: Dimethylaniline	25
4	0.484	0.654	Water: Ethyl Carbonate	25
5	0.592	0.639	Water: Benzene	10
6	0.621	0.636	Water: Benzene	20
7	0.633	0.632	Water: Xylene	25
8	0.636	0.634	Water: Benzene	25
9	0.648	0.634	Water: Benzene	30
10	0.649	0.632	Water: Toluene	25
11	0.709	0.620	Water: Air	25
12	0.837	0.615	Water: Hexane	25
13	0.845	0.616	Aqueous solution of Sodium Chloride: Benzene	25
14	1.071	0.612	Benzene: Air	25
15	1.387	0.620	Aqueous Solution of Strontium Bromide: Hexane	25

tion, but considers that the law of Tate holds for drops which have a 'normal' form. This law he expresses in the form: 'Surface-tension = Constant \times Drop Weight.' The use of this equation is equivalent to the assumption that in figure 1 the curve at the bottom is coincident with its horizontal tangent. From the form of the curve it may be seen that this is not strictly true at any point, but that no serious error is involved in this rule if the determinations of surface-tension are always made with a tip which gives a value of r/a very nearly that at which the tangent touches the curve. Usually the tube used does not meet this very specific requirement, and the result is therefore different from the true result by the distance between this tangent and the curve.

The results of Morgan and McCann⁴ upon 5 different liquids with 16 different tips have been used to calculate the values of the function

$f(r/a)$. Of these only the results obtained on benzene have been plotted in figure 1. This curve is higher than that obtained by us, which means that their values for the surface-tension are less than ours. This, however, does not mean that the drop-weight results given by Morgan and McCann are incorrect, but that the capillary-constant for benzene which they use, and which they do not themselves determine, is lower than that found by us. They use an average constant taken from the results of Ramsay and Shields and other workers. Since the reading of this paper the supposition that these workers have in general obtained too low a capillary-constant has been confirmed by Richards and Coombs,⁵ who considers that the results of Ramsay and

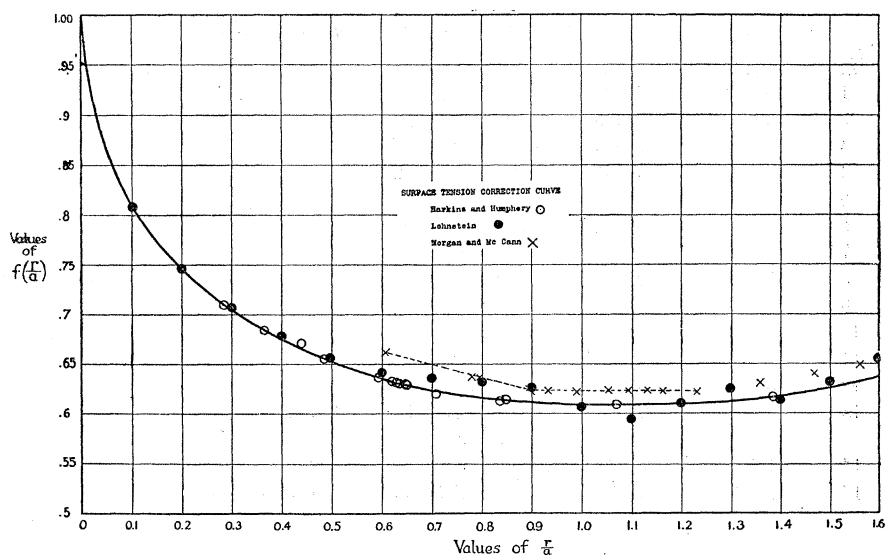


FIG. 1.—(NOTE) THE CURVE HAS BEEN DETERMINED ACCURATELY FOR VALUES OF $\frac{r}{a}$ UP TO 0.7. FOR VALUES GREATER THAN THIS ONLY THE GENERAL FORM OF THE CURVE HAS BEEN DETERMINED.

Shields, Renard and Guye, and Walden and Swinne, are too low, and that the discrepancy is of the order of 3%.

For values of r/a between 0.9 and 1.2 Morgan and McCann get a straight line for the values of the function, which would mean that Tate's law holds. Our determinations in this region have not yet been made with any great accuracy, since most of the work up to the present time has been on values of r/a between 0.3 and 0.7; but at least it can be easily seen that the general form of their curve is very different from ours.

This improved drop-weight method has been applied by us to the determination of the surface-tension at the interface between two liquids, and especially to the problem of the change of surface-tension at such an interface as that between benzene and water when the reaction of the aqueous phase is changed from acid to basic. This problem has been investigated to some extent by von Lerch,⁶ who used the capillary-tube method and thus obtained very poor results.

The problem just referred to has an important bearing on the mechanism of muscular action. Two important facts have been established in regard to the motion of the muscles: first, that the active part of the muscle is always electrically negative to the part at rest, and second, that the active muscle shows an acid reaction. It has been shown by Hill that the amount of energy set free during contraction is directly proportional to the length of the fibrilles, and therefore to the area of their surfaces. According to Bernstein the force of contraction produced by a stimulus has a negative temperature-coefficient. All of these facts seem to suggest that the origin of muscular motion should be sought for in some form of surface energy. This was suggested as early as 1878 by Fitzgerald, who considered that changes of surface-tension are responsible for the phenomenon.

Haber and Klemensiewicz investigated the problem from a physico-chemical standpoint. It may be considered that the fibrilles of the muscles form one phase and the sarcoplasma another phase of a two-phase system. A similar two-phase system was constructed by the use of the interface water-benzene, and it was found that the change of reaction of the aqueous phase from basic to acidic caused a very rapid variation of electromotive force close to the neutral point. The change was found to be of the order of 0.5 of a volt. In similar systems von Lerch had found very rapid changes of surface-tension at the neutral point, so that if his results were reliable there would be a very good physico-chemical basis for the surface-tension theory of muscular action. Such a theory would be that a chemical reaction in the active muscle, such as the production of lactic acid or possibly of carbonic acid, causes the sarcoplasma to become acid, and thus changes the electromotive force, which in turn changes the surface-tension and causes muscular motion.

Unfortunately for this explanation our work indicates that the magnitude of the change of surface-tension at the neutral point is not so great as that found by von Lerch. The data determined by the writers will be presented in later papers to be published in the January (1916) number of the *Journal of the American Chemical Society*.

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¹ Cambridge University Press.

² *Ann. Physik, Leipzig*, Ser. 4, 20, 237-68, 606-18 (1906); *Zs. physik. Chem., Leipzig*, 64, 686 (1908); 84, 410 (1913).

³ 18 papers in *J. Amer. Chem. Soc.*, 30, 33, 35.

⁴ *J. Amer. Chem. Soc.*, 33, 1060 (1911).

⁵ Richards and Coombs, *Ibid.*, 37, 1656-76 (1915); these PROCEEDINGS, 1, 404 (1915).

⁶ *Ann. Physik.*, Ser. 4, 9, 434 (1902).

OUTLINES OF A PROPOSED SYSTEM OF CLASSIFICATION OF THE NEBULAE BY MEANS OF THEIR SPECTRA*

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This paper may properly be considered a continuation of one previously published in these PROCEEDINGS, 1, 266 (1915). In that article the opinion is expressed that the behavior of the line 4686A might serve as the basis of a classification of the nebulae. The notion will be discussed here in greater detail. About eleven of the planetary nebulae have been studied with a fair degree of completeness, and while this number is too low to afford the most secure basis for broad generalizations, the observations seem to point the way to a rational system of classification of these objects on the basis of their spectra.

In figure 1 are reproduced the spectra of nine planetary nebulae and the great nebula in Orion. As stated in the earlier paper the method adopted for observing the spectra of such nebulae consists in placing the slit of the spectrograph directly across the image. In this way the length of a spectral line is made to furnish a measure of the extent of the occurrence of the emitting material in the nebula.

The first spectrum shown is that of N. G. C. 7027. This nebula consists of two nuclei, of unequal brightness, surrounded by fainter nebulosity. In photographing the spectrum the slit was placed in the line of the two nuclei. The spectrum shows the nebula to be unusually homogeneous. Some of the fainter lines appear to be short but that is probably merely the result of their faintness, as they are no shorter than the

* This and the following paper contains, in abbreviated form, the substance of one read before the eighteenth (Pacific Coast) meeting of the American Astronomical Society, under the title: *The spectra of the gaseous nebulae and some points of correspondence between them and other celestial spectra.*